

Uncertainty and the Markets for Water Pollution Control

by

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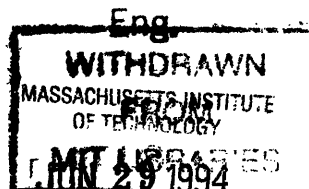
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ABSTRACT

Market-based instruments for pollution control have received large attention during the last years due to increasing costs of pollution abatement and the need for more flexibility among emitting sources to comply with environmental regulations. The evidence, however, has shown some implementation problems with such instruments. A classic example of such problems is the Fox River permit program, in Wisconsin. This thesis focuses on the performance of transferable discharge permits (TDPs) for water pollution control, in particular biochemical oxygen demand (BOD) discharges.

Uncertainty and transaction costs, among others factors, can adversely affect the trading activity in a market for water pollution as well as in others. Uncertainty comes from the fact that regulatory authority needs directly or indirectly to intervene within market to prevent future violations in the water quality standards, and also by the fact that permit prices do not necessarily remain constant over time. The effects of uncertainty and transaction costs are studied by using two models: (1) a one-period model that shows how authority's approval requirements can affect trading activity; and (2) a two-period model that shows how a conditional TDP system that accounts for price variability affects irreversible investments in wastewater treatment capacity and hence trading incentives.

The study concludes that trading incentives can be significantly reduced by these adverse factors. Despite them, however, TDPs still can offer more cost-effective solutions than command-and-control approaches in dealing with the water pollution problem. We also include some policy implications regarding these matters.

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I. INTRODUCTION

Market-based instruments for pollution control have received large attention during the last years due to increasing costs of pollution abatement and the need for more flexibility among emitting sources to comply with environmental regulations.¹ Marketable permits is one of the most attractive of such instruments for being both cost-effective and environmental quality based. It has been considered and used for different environmental regulatory purpose including water pollution control.² Despite the large "potential" savings estimated from water pollution markets the evidence tells us that trading activity has been quite low. Uncertainty, among others factors, can adversely affect the trading activity. In a market for water pollution control uncertainty may come from the fact that regulatory authority needs directly or indirectly to intervene to prevent violations in water quality standards due to market activity. This thesis is concerned with the role of that uncertainty in explaining, at least partially, the low activity in the water pollution markets.

Much of the literature on permits for water pollution control focuses on the potential savings of using this regulatory approach over the traditional command-and-control approach.³ O'Neil (1980) analyzed the use of a transferable discharge permit (TDP) system to reduce discharges of biochemical oxygen demand (BOD) among 14 polluters in the Lower Fox River. The study concluded that the abatement costs to

¹ Nominal pollution control expenditures in the United States have risen from \$18 to \$78 billion during the period 1972-1986. Currently, about 2% of the entire gross national product is used to address environmental problems (Hahn, 1989b, p.3) and it is expected to rise up to 2.6% by the end of the century.

² See Hahn (1989a), Hahn (1989b, pp .23 and 46-47), and Moore et al (1989) for a description of existing marketable permits programs.

³ The command-and-control approach consists basically in two instruments: technology and emission standards. The Clean Water Act currently provides a two-tiered approach to water quality protection. At a minimum, technology-based requirements limiting pollutant concentrations in effluents must be attained by all point source discharges. These requirements takes the form of nationally uniform standards for classes and categories of industries, and a parallel approach for publicly owned treatment works (POTWs) and their indirect discharges. For more detail see Portney (1990), and U.S. EPA (1992).

achieve the dissolved oxygen (DO) level targets would be about 40% higher if the authority were to rely in a uniform emission (discharge) standard approach. Similarly, David et al. (1980) concluded that TDPs can be used to control phosphorous effluent into Lake Michigan at costs that approach the minimum. Furthermore, savings can be even larger by taking into account the variability of the water bodies assimilative capacity under a dynamic TDP system.⁴ O'Neil (1983) used three period flow patterns to estimate potential savings for the Fox River. Using a dynamic TDPs system original savings can increase up to 48%. Eheart et al. (1987) showed that by using a similar approach to control BOD discharges in the Willamette River, Oregon, savings can account from 58% to 80% (in total costs) compare to the uniform percent BOD removal. Despite these large potential savings, only a few programs for water pollution control have been implemented in practice and the results have not been promising. Indeed, markets for water pollution have poorly performed compared to the criteria air pollutants trading program and the successful lead trading program (Hahn, 1989b).⁵

Among the water programs which deserves much attention is the Fox River case in Wisconsin. Since September 1981, when the Wisconsin Legislature gave final approval to administrative regulations that provide the possibility for trading permits to discharge BOD on water quality-limited stream segments, only one trade has occurred. Why? This thesis intends to help with the answer, at least partially. Furthermore, other markets for water pollution control have experienced the same fortune. A trading program between point and nonpoint sources for Dillon Reservoir, Colorado, was

⁴ The potential for increased benefits through dynamics programs is considerable. Savings in capital and operating costs may result from programs that allow relatively large discharges during times when receiving bodies are able to assimilate relatively large waste loads. Such cost savings may justify tightening standards during the critical periods. However, the savings of using dynamics transferable permits varies from watercourse to watercourse.

⁵ The criteria air pollutants trading program started more than a decade ago and covers volatile organic compounds, carbon monoxide, sulfur dioxide, particulates and nitrogen oxides. The lead trading program, created in the past decade, allowed gasoline refiners greater flexibility during a period when the amount of lead in gasoline was being significantly reduced. For more details about these two programs, see Hahn (1989a), Hahn (1989b, pp. 46-47), Moore et al. (1989), and Hahn and Hester (1989).

implemented in order to reduce phosphorous discharges to the reservoir. This program has witnessed only one nonpoint-nonpoint trade since 1984 (U.S. EPA, 1992). Despite each program is different, it is important to develop a general understanding of the necessary conditions for these markets to perform well specially when large attention is now given to TDP systems for water pollution control that includes both point and nonpoint source trading, and for other environmental problem as well.⁶

Several authors have focused on the conditions that might affect the trading activity in the markets for water pollution control and eventually others (Rose-Ackerman, 1977; David and Joeres, 1983; and Moore et al., 1989). There are more than few factors that could adversely affect the market performance. First, the pre-existing regulatory framework. A TDP system that constitutes a small part of the current regulatory structure must be incorporated into the policy decisions on much broader scope (David and Joeres, 1983). Second, monitoring and enforcement. Inappropriate monitoring and enforcement capabilities may lead to discharges to operate near their permitted limits having no incentive to trade (David and Joeres, 1983).⁷ Third, "market conditions" such as low number of participants, strategic behavior, non-profit maximization behavior, and transaction costs (O'Neil, 1980; Stavins, 1994).⁸ Finally, uncertainty coming from authority intervention in the market.

Although a TDP system reduces the level of "confrontation" between regulator and the regulated, the involvement of the authority can not be totally reduced because of technical and political conditions associated with the water system (David et al., 1980). Any water agency that faces the two-dimension problem of assuring a certain

⁶ See U.S. EPA (1992) for water; Nichols (1993) for SO₂; and Bohm (1993) for CO₂.

⁷ Penalties in violations must be immediate, known a priori and large in relation to marginal treatment costs, and enough to not threaten the existence of the enterprise (David and Joeres, 1983).

⁸ Among the above we only consider transaction costs. We assume for the moment that agents are profit maximizers and that there is a sufficient number of potential traders. Note, however, that markets for water pollution are rather small and usually include public utilities. The latter makes TDP even less attractive.

environmental quality level and of reducing the regulatory burden on polluters will need at some point to intervene within the market either through direct action (e.g. controlling transfer approval) or through indirect action (e.g. indexing emission rights to watercourse conditions).

In not considering the factors that can adversely affect the trading activity of a marketable permit system, potential savings will always be overestimated. Tietenberg (1985), in a frequently cited table, showed that the ratio of the cost of the actual command-and-control program to a least-cost benchmark for each case ranged from 22.0 to 1.1. A more realistic comparison, however, should be between actual command-and-control policies and either actual trading programs or a reasonable constrained theoretical permit or charge programs (Hahn and Stavins, 1992). Among the few attempts that incorporate some of the above factors into a model of marketable permits is Stavins (1994), which studies the effects of transaction costs. However, uncertainty has only been mentioned throughout the literature with no attempt to model it and hence estimate its importance. In this thesis, rather than comparing the importance of the different factors, we want to show that uncertainty at different forms can adversely affect the economic incentives of the participants and thus the trading activity.

In doing so, we organize the thesis as follows. The next section gives an overview of the water pollution problem with special emphasis on BOD discharges, and the need for agency intervention in a TDP system. We also illustrate the practical importance of agency intervention in existing (e.g. the Fox River) and proposing TDP programs. In section III, we model both direct and indirect authority intervention and the effects on a purchaser of TDPs to control BOD. The effects are reflected in the level of control and in the treatment plant capacity choice. In section IV we develop some additional issues regarding both direct and indirect intervention. Policy implications and final remarks are given in V.

II. THE WATER POLLUTION PROBLEM

One of the most important decisions planners must make in designing any water quality management program for a particular water body is the form and stringency of the water quality goal (David and Joeres, 1983). A set of both water pollution and receiving body conditions shapes the authority's decision regarding the water quality goal and the way to ensure it over time. Due to these conditions, authority intervention within a market for water pollution control may be required throughout the program implementation. The nature of authority intervention and the effects on market performance are illustrated in this section.

Defining water pollution is not such a simple task because there are many different substances that can be dissolved or suspended in water. Usually waste discharges are a mixture of different substances. Much of the material, however, is biochemical oxygen demanding waste, but other substances include suspended solids, acids, pathogens, toxic metals, toxic organic chemicals, nutrients that can generate algae blooms, and so on.⁹ A second definitional difficulty with water pollution is that it is relative to the consumer. Nobody "consume pollutants" directly upon discharge. The relationship between water uses and the waste emitted by any single discharger is not a simple one. It depends on the characteristics of the stream, the season of the year, the year, the location of discharges relative to users of water, and the location and waste discharges of other polluters. All this complexity can have effects on the implementation and performance of any market for water pollution.¹⁰

The importance of the complexity of the water pollution problem on a potential market have been commented by a number of authors. Rose-Ackerman (1977) was one of

⁹ A good description of water pollutants and their sources is found in Davis and Cornwell (1991, pp. 261-309).

¹⁰ Much of this analysis may also apply to other non-conservative pollutants (e.g. NO_x).

the first that point out that a market system cannot simply levy a price on pollution but must deal with a number of different substances. Thus, in the case of considering a market for a single pollutant such as biochemical oxygen demand (BOD), regulator supervision may be needed to control the flow of others pollutants with each transfer of the above pollutant.¹¹ Therefore, in a transferable discharge permit (TDP) system for BOD control direct intervention in the form of transfer restrictions may be necessary to prevent violation of water quality standard regarding other pollutants including toxic substances.

The location of discharges relative to users of water, and the relative location and waste discharges among polluters has significant implications on water quality levels. Unlike conservative substances, BOD discharges affect water quality according to their location magnitude.¹² For illustration of the location problem, think of a TDP program for BOD control.^{13,14} For example, consider a TDP that allows to discharge "k" pounds of BOD daily at location "A" on a given river. Consider also a point "Z", critical point, where dissolved oxygen (DO) is at its lowest level along the section of the river under consideration. If the TDP is sold and the discharge site changes to location "B", then the impact on DO level at "Z" can considerably change because of differences in the time of flow and other stream parameters. It can also occur that "Z" is not longer the critical

¹¹ This is specially important when there is a flow of toxic substances creating hot spots. In theory we can think of a water pollution market that considers different pollutant at the same time, however its implementation would be very difficult (Rose-Ackerman, 1977).

¹² For more conservative pollutants (e.g. phosphorous) location should not affect much.

¹³ Permits for BOD control can be defined in two forms. The first called a BOD permit, entitles the holder to discharge a certain mass of BOD per day. This type of permit is usually known as emission permit system. The second type of permit entitles a discharger to deplete the dissolved oxygen (DO) at a specific location in the watercourse. This point usually corresponds to the critical point, where DO level is the lowest. This latter is called a DODC permit (dissolved oxygen deficit contribution) and it corresponds to an ambient permit system. Both type of permits are considered as transferable discharge permits (TDP).

¹⁴ There are cases where BOD load permit system (emission permit system) could be as efficient as a DODC permit system (see 13 above). For example, Eheart (1980), showed that for the Willamette River the difference in cost was at the most 3% depending on the level of control. For this case a emission permit systems is preferred to an ambient permit system because both it is easier to administer and the difference in cost is very little.

point, but a new point "W". An unrestricted permit transfer or set of transfer in a more complex setting could cause a violation of DO standards unless some type of pre-approval requirement is considered.¹⁵

A final very important aspect is the variability conditions of the assimilative capacity of the watercourse.¹⁶ O'Neil (1983) studied a market permit system to control BOD in the Fox River under conditions of varying streamflow and temperature. Eheart et al. (1987) studied the cost efficiency of time-varying discharge permit programs for BOD control.¹⁷ Both studies concluded that including the variability aspect into the TDP models, extra savings can be obtained whereas environmental quality is maintained. The authors, however, considered only a periodic TDP system where flow and temperature vary in a predictable sequence over the course of an annual cycle. This is a perfect foresight. Unfortunately, variation of the streamflow rate over the years may be larger than seasonal variations within a year.¹⁸ Under the periodic TDP system, the authority, and thus society, assumes all of the risk associated with unpredictable fluctuations in natural stream conditions, since water quality may turn unacceptable even though the dischargers meet all requirements. The dischargers themselves assume none of the risk, since their allowable effluents rates are fixed for an annual cycle (Eheart et al., 1987). The authority, however, could assure environmental quality over the years by controlling the transfer activity through, for example, a conditional permit system -- indexing discharge rights to ambient conditions.

¹⁵ Most of these complications can be reduced in part by using an ambient permit system. However, changes in critical points and hence violations can still occur. All this depends finally in conditions given by the water body and the locations of the emitting sources.

¹⁶ The rate of streamflow and temperature are the two the most important physical parameters that affect the capacity of a stream to assimilate BOD effluent. See O'Neil (1983).

¹⁷ Eheart et al. (1987) proposed, for example, that allowable discharge permits might be proportional to the streamflow.

¹⁸ This property varies from river to river and it depends on physical and hydrological conditions. For example, seasonal variations of the rate of streamflow for the Fox River are significantly smaller than variations over the years; see O'Neil (1980, p.119).

Different types of transfer restrictions can be used by the authority to prevent violation in the water quality standards, some more direct than others.¹⁹ Among the alternatives, the ad hoc approval approach is the most common. Under this approach any TDP exchange must be approved by the water pollution control authority (Eheart et al., 1983). The Fox River TDP program, in Wisconsin, implemented to control BOD discharges is an illustrative example of ad hoc approval mechanism (David and Joeres, 1983). U.S. EPA (1992, p.22) also comments about the Fox River program as:

"Numerous administrative requirements also added to the cost of trades and decreased incentives for facilities to participate. Wisconsin Department of Natural Resources (WDNR) must approved the proposed trades and modify the permits of the trading facilities. This process can take a minimum of six months. The lengthy permit revision process further reduces the value of the potential discharge allocations. Additionally, transaction costs from trading became prohibitively high because there was no brokering or banking function. The administrative approval process is also complicated by the fact that the pollution problem is not limited to BOD, but includes toxic organic compounds from paper mill effluents. Some proposed trades might have led to high local concentrations of toxic pollutants and may not have passed administrative review."

Eheart et al. (1983) also notices the adverse effects under the ad hoc approach by increasing transactions costs and administrative costs for the water quality agency (which can be passed to TDP buyers and sellers in the form of transactions costs as well). Also, dischargers could face the expense of countering public opposition whether it materializes or not representing significant time delays. The presence of additional transactions costs and the uncertainty about the transfer approval, and their effects on dischargers' decision regarding TDP exchanges are the topics of the first model in section III.

In some cases indirect authority intervention is an alternative for preventing future violations. These are types of transfer restrictions that place general constraints on exchanges, but do not require as much administrative burden on each exchange as the ad

¹⁹ Eheart et al., 1983 studied the following approaches to prevent or to reduce the likelihood of violations of a given water quality standard: ad hoc approvals, limiting the number of permits, limiting the aggregate discharge in subregions of the watercourse, preventing transfers across geographical boundaries, revaluing the permits automatically and uniformly when exchanged, and using combinations of these approaches.

hoc approval approach.²⁰ Restrictions could be applied in the context of a decentralized market or in the context of a systematic trading sessions organized, for example, by the water agency (Eheart et al., 1983). For example, the use of a conditional permit system would allow the authority to account for future changes in stream conditions. It would be able to increase or decrease the total quantity of permits at the end of each period if the previous calculations as to the assimilative capacity appear to be too lenient or too stringent. TDPs are then issued for a limited period, and their transfer is in effect a lease rather than a sale alienating the right forever (David et al., 1980).

Unfortunately, under this approach the purchase of TDPs would not be riskless. Under conditional permits more responsibility for water quality maintenance is borne directly by the discharges. Unlike periodic TDP system, dischargers' investment decisions under conditional permits will have to account for uncertainty in the frequency, duration, price, and stringency of future treatment requirements and the penalty for violating those requirements (David et al., 1980; and Eheart et al., 1987). Prices are subject to change if a conditional TDP system is implemented. In addition, prices may either rise as population and industrial development increases or fall as cheaper control technology is developed. This uncertainty in future prices may induce all operators to install treatment facilities as a hedge against the risk of high-cost rights in the future or to refuse to lease their excess TDPs (David et al., 1980).²¹ The effect of price uncertainty on the installed capacity choice decision is treated with the second model in section III. Particularly, we are interested in how reversible (purchasing of TDPs) and irreversible investments (waste treatment facilities) are affected by TDP price uncertainty.

²⁰ Some of these are: limiting the aggregate discharge in subregions of the watercourse, preventing transfers across geographical boundaries, revaluing the permits automatically and uniformly when exchanged.

²¹ David et al. (1980) referred only to more conservative operators.

III. THE MODEL

Dales (1968) was the first in propose the idea of using tradable emissions rights to distribute the pollution-reduction burden among firms in a cost-effective manner. Once property (emission) rights are clearly defined it is expected firms to trade and eventually reach the cost-effective equilibrium. This is possible, as pointed out by Coase (1960), only in absence of transaction costs. Throughout this section we will show how transaction costs and uncertainty impede to reach such an equilibrium. Before move on, I should mention that the cost-effective solution is derived in the appendix.

We will consider two cases of trading from the perspective of a purchaser of TDPs that must comply with BOD standards: (1) trading under the ad hoc approval mechanism, which includes transaction costs and uncertainty about the approval; and (2) trading under a conditional permit system, which includes irreversible investment (waste treatment facilities) and permit price uncertainty. Transaction costs are not considered in the latter case.²²

3.1 Uncertainty , Transaction Costs and the Ad Hoc Approval Approach

The desirability of seeking TDPs to control BOD discharges will depend on the amount of savings from using the TDP option and the probability of success in the transfer. A one-period model formulated in decision theoretic perspective is used to analyze the investment decision faced by a firm regarding level of pollution control and TDPs. A similar approach was used by Lund (1993) to study the effects of transaction risk on the desirability of water transfers.²³ The investment decision problem studied here

²² The analysis can be easily extended for the case of a seller [of permits].

²³ Lund (1993) notices that uncertainty of water transfer approval can have several origins: (1) one or more state water right regulators must approve a potential water transfer that is by no means certain; (2) even where regulatory approval is likely, there may be court challenges to the transfer based on regulations or environmental impacts; and (3) the threat of controversy and expense from regulatory or court challenge

is by no means unique to these markets, but it applies to any situation where transaction costs and uncertainty are likely to occur.

Consider an individual firms (buyer of permits) that receives a certain amount of BOD discharge rights, q_0 , freely distributed by the authority,²⁴ that can be exchanged. Assume also that penalties from violations are so high that individuals do not consider them as any mean of compliance. Under these circumstances, those firms seeking TDPs will consider the costs of compliance in present value terms. These costs can be grouped into three categories: pollution abatement costs, costs of purchasing TDPs, and transaction costs. Capital and operational costs of pollution abatement are assumed to be certain and equal to C_A . This value will depend on the amount of BOD controlled or reduced by the emitting source. This amount is denoted by r . Thus, we have $C_A = C_A(r)$. This a twice differentiable, convex and increasing function.²⁵ Costs of purchasing TDPs, C_P , is given by the price, p , of each permit, and the number of permits, x . For a buyer of TDPs whose unrestricted emissions or discharges are equal to u , x corresponds to

$$x = u - r - q_0 , \quad (1)$$

where x , u , r , and q_0 can be measured in kg/day of BOD. In order to comply with the regulations eq. (1) must hold all the time. Before explaining the nature of transaction costs, let me add that at this point, the individual firm faces two options to comply with environmental standards. The first is to disregard TDPs and to control BOD discharges by $u - q_0$ units, at a total cost equal to $C_A(u - q_0)$. The second option is to buy some TDPs and to control at a lower level. The second option, however, is uncertain by reasons

can dissuade potential buyers from continuing the pursuit of water transfers. He also suggested that many of these features may occur in transfers of water pollution rights.

²⁴ The method of distribution can also have impacts on the market performance; see Eheart et al. (1980).

²⁵ This assumption is valid for most pollution control cost functions. See Tietenberg (1992, pp. 360-391).

detailed in previous sections. Then, there is a probability of success, P_s , in getting the transfer approval from the water agency.

The desirability of seeking TDPs to control BOD discharges will not only be subject to P_s , but also to those costs associated to the exchange of any property right; the transaction costs. They are present because parties to potential exchanges must find one another, communicate, exchange information, do legal and technical work to support the transfer, face approval's delays, etc.²⁶ The transaction costs of any potential exchange of TDPs to control BOD may be divided in two parts: the transaction costs to support the transfer approval, T_A , and the additional transaction costs borne after the approval and required to complete the transfer, T_T . T_A would include the expected value of the resources spent to support a transfer before it is approved or rejected. The resources are in the form of technical, administrative and legal work accompanied by lengthy approval processes.²⁷ Much of the bargaining, searching and information expenditures are included in T_A as well. T_T , borne when the approval is obtained, would include some additional technical work but specially the legal work associated to the exchange itself. Although there may be a sublet distinction between the nature of T_A and T_T , there is a clear distinction about the economic return of each one. If the transfer is rejected, the return from T_A is zero. Later in the thesis we come back to the distinction between T_A and T_T .

If an amount x of TDPs is attempted and succeeds the total cost of compliance (in present value terms) is given by $T_A + T_T + C_A(r = u - x - q_0) + C_P(x)$, where r is obtained from eq. (1). Hereafter we will use just r to refer $u - x - q_0$. If the attempted transfer fails, the total cost (in present terms) is given by $T_A + C_A(u - q_0)$. The choice of seeking TDPs is illustrated by the decision tree in Figure 1.

²⁶ Transaction costs are also evident because the need to inspect and measure the goods to be transferred, draw up contracts, consult with lawyers and others experts, transfer title, etc. A good description is in Stavins (1994).

²⁷ Third parties such as companies with no access to the permit system and environmental groups can have some effect on the decision making process. Additional future exchanges can be affected by this one, so companies in the system can influence the process as well.

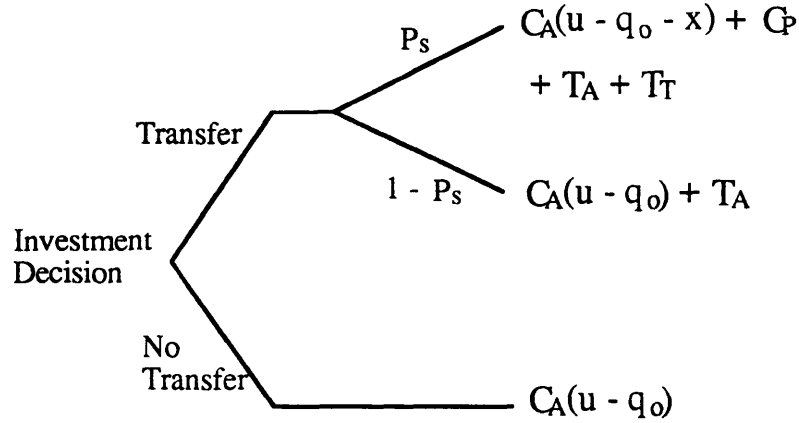


Figure 1. Decision tree corresponding to investment alternatives for BOD control under conditions of uncertainty about the approval (P_s) and transaction costs (T_A and T_T).

The choice is reduced to two options: one with TDPs given by

$$TEC_T = P_s \cdot (C_A(r) + C_P + T_A + T_T) + (1 - P_s) \cdot (T_A + C_A(u - q_0)), \quad (2)$$

where TEC_T is the total expected cost of BOD control with "transfers," and C_P is equal to $p \cdot x$, with p assumed exogenous (for thin markets this latter observation may not hold).

The second option that does not consider TDPs is given by

$$TC_{NT} = C_A(u - q_0). \quad (3)$$

where TC_{NT} is total cost of compliance with no "transfers." A risk neutral agent will attempt the transfer option as long as $TEC_T < TC_{NT}$.²⁸ If $TEC_T = TC_{NT}$ such agent will be indifferent between the two options. There is, however, a first necessary condition for the TDP option to be desirable, that is $C_P + C_A(r) < C_A(u - q_0)$. This necessary, but not

²⁸ A risk averse agent will include a risk premium making TC_T to increase.

sufficient, condition implies that in the absence of transaction costs, the TDP option could be pursued only if there is some savings, ΔC , given by

$$\Delta C = C_A(u - q_0) - C_A(r) - C_P. \quad (4)$$

The expected present value of total cost savings from considering the TDP option is expressed by the difference between TC_{NT} and TEC_T . Using eq. (2) and (3) leads to

$$\begin{aligned} TC_{NT} - TEC_T &= C_A(u - q_0) - P_s \cdot (C_A(r) + C_P + T_A + T_T) \\ &\quad - (1 - P_s) \cdot (T_A + C_A(u - q_0)), \end{aligned} \quad (5)$$

and if we rearrange terms and use (4), we obtain a new expression for (5) given by

$$TC_{NT} - TEC_T = (\Delta C - T_T)P_s - T_A. \quad (5a)$$

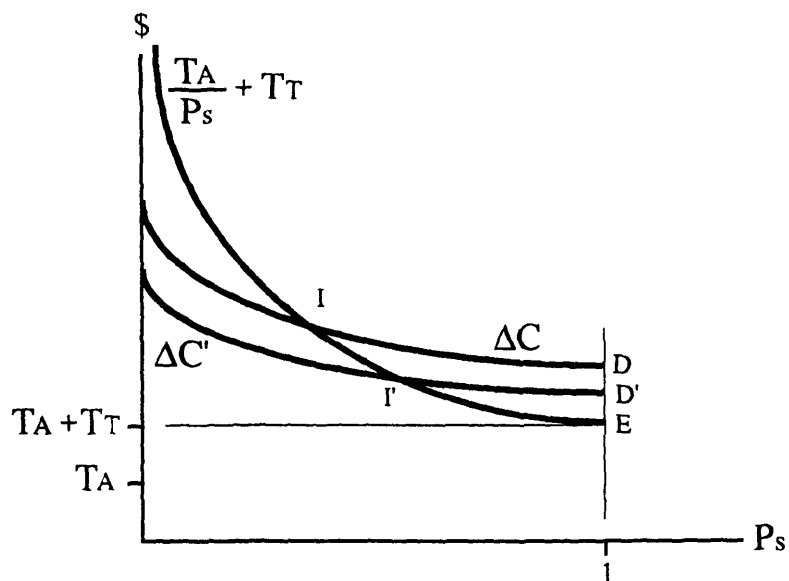
If $TC_{NT} - TEC_T$ is equal to zero, a risk neutral agent will be indifferent between the two options. Then, an indifference point can be established by setting (5a) equal to zero. This yields to

$$\Delta C = \frac{T_A}{P_s} + T_T. \quad (6)$$

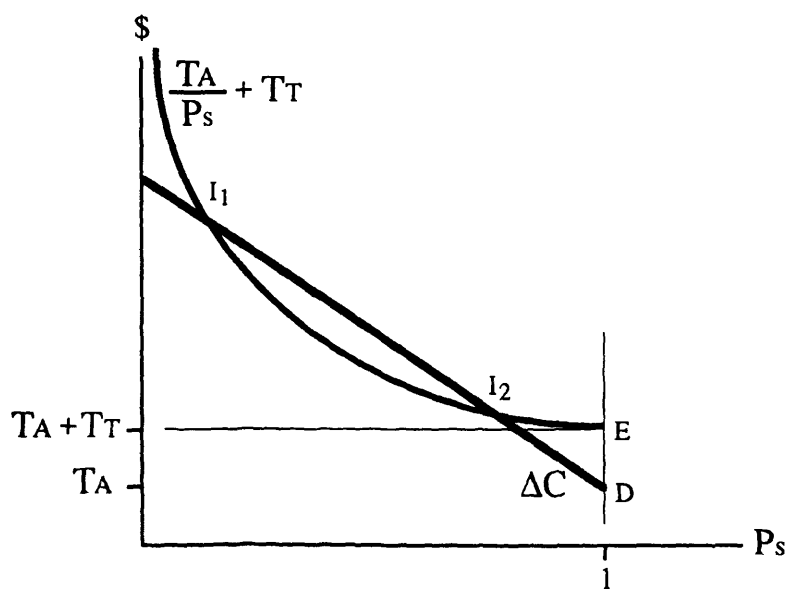
Eq. (6) shows the importance of uncertainty in the transfer approval (P_s) and the distribution of transaction costs before and after the approval (T_A and T_T respectively) for the decision process of any potential buyer of TDPs. Initial savings in absence of transaction costs, ΔC , can be reduced at a point where the TDP option is not longer attractive.

A numerical example gives us better understanding of the decision investment situation. Consider initial savings (in absence of transaction costs) $\Delta C = 100$, and probability of success $P_s = 0.5$. Additionally assume that only 20% of initial savings will be spent on transaction costs after the approval ($T_T = 20$). Under these circumstances a risk neutral rational agent would be willing to spend at most 40% of the initial savings in transaction costs associated to the approval ($T_A = 40$). Under conditions of certainty, conversely, the same agent would be willing to pay up to 80% of the initial savings.

The importance of the result is also illustrated in Figure 2. Given T_A and T_T (assumed fixed amounts at this point), we can draw the indifference curve $T_A/P_s + T_T$. Additionally we can draw a curve $\Delta C = \Delta C(P_s)$. We can expect that ΔC is a decreasing function in P_s because as ΔC decreases trading opportunities increases (larger number of potential partners) and so does P_s . The exact shape of the curve, however, is of no importance to illustrate the issue. Later in the thesis we will discuss some relationship between amount of trading and transaction costs. In Figure 2(a), the point where both curves crosses, I, is the indifferent point. To the right of I, the transfer attempt will be pursued because the expected gains of using the TDP option are greater than zero. If instead we consider a risk averse agent, which is very realistic for public utilities and some private firms, ΔC shifts down by an amount equal to the risk premium obtaining $\Delta C'$ and a new indifferent point I'. The effects of risk adversity is to discourage transfer attempts even more. As a complement, in Figure 2(b) we present a different ΔC curve where transfer attempts are feasible only between I_1 and I_2 (for a risk neutral agent). The shape of ΔC will finally determine the level of expected transfer attempts and hence trading activity.



(a)



(b)

Figure 2. The TDP option will be attempted when ΔC is greater than $T_A/P_s + T_T$ (for a risk averse agent consider $\Delta C'$). In case (a) this occurs to the right of I , while in (b) it occurs between I_1 and I_2 . The shape of ΔC will finally determine the range where attempts are feasible.

Interaction between regulator and regulated

The preceding analysis assumes that the probability of success, P_s , is independent of the amount of effort agents devote to make the transfer successful. In reality there is an interaction between agents and the corresponding authority that may affect P_s . This interaction will be subject to the technical and political conditions related to both the transfer and the water system. For example, a low amount of TDPs being exchanged in a system where location does not considerably affect the configuration of critical points is more likely to succeed.²⁹ We assume here that the probability of success, P_s , will be subject to the amount of TDPs, x ; and the amount of effort spent by the agent during the transfer approval process, T_A . Eheart et al., (1983) suggested that the ad hoc approval approach could be formalized by approving TDP exchanges whenever the buyer or seller could demonstrate that no new violation of the water quality standard would occur. The amount of technical work that this will require is part of T_A . Additionally, an agent may be willing to compensate third parties for some negative effects.³⁰ Finally, it is expected that these frictions decrease as the amount of TDPs does. Therefore, there is functional form (unknown) for P_s as $P_s(T_A, x)$.

The function $P_s(T_A, x)$ will be assumed to be continuous throughout the domains of its variables, twice-differentiable respect to T_A and x .³¹ Additionally, P_s it is assumed to be an increasing function in T_A , and decreasing function in x . These conditions are

²⁹ Eheart (1980), for example, points out that the location of the critical points for dissolved oxygen (DO) level for the Willamette River in Oregon would be always the same regardless the combination of BOD treatment level of the eleven discharges.

³⁰ Eheart et al. (1983) notices that "inefficiencies" could arise when potential transfers are evaluated independently. For example, two possible transfer could be independently acceptable, but unacceptable in combination. In this situation one firm may be willing to compensate others in order to go ahead with the transfer.

³¹ It might be the case of a discontinuous function (Lund, 1993).

$$\frac{\partial P_s(T_A, x)}{\partial T_A} > 0, \text{ and } \frac{\partial P_s(T_A, x)}{\partial x} < 0. \quad (7)$$

There is final aspect regarding functional form of transaction costs that deserves mention. There is evidence that transaction costs, T_A and T_T , and the amount of TDPs, x , are related.³² We assume increasing functions in x , but recognizing that part of T_A and T_T may be fixed (or independent of x). To better understand, think of a total amount of transaction cost $T_C = T_A + T_T$ that increases in x , and in which T_A and T_T have to be distributed between before and after approval. Notice that T_A and T_T need not to be perfect substitutes -- there are some expenditures exclusively associated with T_A . Eventually, you can manage to increase T_A without changes on x , in order to increase the probability of success, P_s . The effects of different functional forms are discussed in section IV.

This interaction between regulator and regulated leads to a subsidiary decision making problem (Lund, 1993). Assuming that an agent is choosing the TDP option to comply with regulations, they now will estimate the amount of them that can make the transfer successful. Using an expected monetary value decision criterion, we next analyze the optimal allocation of resources made by a buyer of TDPs. By substituting $P_s(T_A, x)$ into eq. (2) leads to

$$TEC_T = P_s(T_A, x) \cdot (C_A(r) + C_P + T_A + T_T) + (1 - P_s(T_A, x)) \cdot (T_A + C_A(u - q_0)), \quad (8)$$

where TEC_T is the expected total cost, and T_A and x are our decision variables. While T_A affects only P_s , x affects P_s , $C_A(r)$, C_P , T_A , and T_T . Replacing $C_A(r)$ by $C_A(x)$ according

³² Stavins (1994) defines a common transaction cost function, $tc(x)$, for which $tc'(x) > 0$, and for which $tc''(x)$ may be positive, negative or zero-valued. He gives a good description about the nature and effects of different transaction costs functions.

to (1), and minimizing TEC_T by setting the derivatives respect to x and T_A equal to zero, we obtain that

$$\begin{aligned} \frac{\partial TEC_T}{\partial x} &= \frac{\partial P_s(T_A, x)}{\partial x} (C_A(x) + C_P(x) + T_T(x) - C_A(u - q_0)) \\ &\quad + P_s(T_A, x) \cdot \left(\frac{\partial C_A(x)}{\partial x} + p + \frac{\partial T_T(x)}{\partial x} \right) + \frac{\partial T_A(x)}{\partial x} = 0 \end{aligned} \quad (9)$$

$$\frac{\partial TEC_T}{\partial T_A} = \frac{\partial P_s(T_A, x)}{\partial T_A} (C_A(x) + C_P(x) + T_T(x) - C_A(u - q_0)) + 1 = 0. \quad (10)$$

Rearranging terms and dividing (9) by (10) leads to

$$\frac{\partial C_A(x)}{\partial x} + p + \frac{\partial T_T(x)}{\partial x} + \frac{\partial T_A(x)}{\partial x} \frac{1}{P_s} = \frac{\partial P_s / \partial x}{\partial P_s / \partial T_A} \frac{1}{P_s}, \quad (11)$$

and we know, by the chain rule and (1), that in the case of a purchaser of TDPs we have that

$$\frac{\partial C_A(r)}{\partial r} = \frac{\partial C_A(x)}{\partial x} \frac{\partial x}{\partial r} = - \frac{\partial C_A(x)}{\partial x}. \quad (12)$$

and replacing (12) into (11) we finally obtain an equilibrium solution given by

$$\frac{\partial C_A(r)}{\partial r} = p + \frac{\partial T_T(x)}{\partial x} + \frac{\partial T_A(x)}{\partial x} \frac{1}{P_s} - \frac{\partial P_s / \partial x}{\partial P_s / \partial T_A} \frac{1}{P_s}. \quad (13)$$

where the last term represents the interaction effect. Eq. (13) implies that in contrast to the cost-effective or least-cost solution (detailed in the appendix), in this case we obtain that agents would control pollution at a marginal cost equal to the "sum" of permit prices, marginal transaction costs and a risk component. The total cost of pollution control, however, would be the sum of capital and operational costs, transaction costs, and the

amount of TDPs purchased. Then, risk has an indirect effect on the total cost of control by affecting the level of pollution control r . In other words, risk can not be considered as an incurred cost, rather as forgone benefit.

In order to better understand the implications of eq. (13), it is useful to show two particular cases. First, if P_s is given and independent of x and T_A eq. (13) reduces to

$$\frac{\partial C_A(r)}{\partial r} = p + \frac{\partial T_T(x)}{\partial x} + \frac{\partial T_A(x)}{\partial x} \frac{1}{P_s}. \quad (13a)$$

Notice the similarity with (6). Second, if agents are always certain about the approval, which means the P_s is independent of x and T_A and equal to 1, equation (13) becomes

$$\frac{\partial C_A(r)}{\partial r} = p + \frac{\partial T_C(x)}{\partial x}, \quad (13b)$$

where T_C are the total transaction costs equal to $T_A + T_T$. This latter is the result obtained by Stavins (1994), who in addition considers different transaction costs functions and studies the importance of the initial allocation, q_0 , when transaction costs were non-zero. In this thesis we certainly consider such transaction costs, but we rather focus on the effects of uncertainty in the equilibrium solution.

By first looking at eq. (13b), we see that the original cost-effective or least-cost solution will not be achieved. It is clear that if marginal transaction costs associated with the transfer are non-zero, the purchaser of TDPs will choose for more pollution reduction -- higher level of r -- and lower amount of x . This is because the marginal cost of pollution control and the marginal transaction cost increase increases with r and x respectively. In the aggregate level, BOD discharges will be lower than in the absence of transaction costs. Since, usually transaction costs are considered real resource costs, we may refer to this new equilibrium -- eq. (13b) -- as a "cost-effective equilibrium in the presence of transaction costs." Notice, however, that the new cost-effective solution

involves greater aggregate costs of compliance compare to the "cost-effective solution in absence of transaction costs." The important issue is then to estimate the true costs of control and hence the real potential savings.

Now, by looking at equation (13a) we find that uncertainty makes the true costs of control even higher. As long as $P_s < 1$ the level of BOD control will be even higher and the amount of trading lower. Although uncertainty does not absorb resources directly it suppresses incentives for trading what leads to an equilibrium solution even further from the "cost-effective solution in absence of transaction costs." Finally, by looking eq. (13) again, it seems that the situation gets even worse (in terms of overall costs) because the interaction term is negative ($\partial P_s / \partial x < 0$ according to (7)). However the presence of an interaction term has ambiguous effects on the level of control r -- it could be the same, higher or lower, but never as in (13b). This ambiguity comes from the fact that agents can manage T_A making the transfer more or less likely and the fact that changes in x or T_A affect P_s differently. Agents behavior will finally depend upon the functional forms assumed for $P_s(T_A, x)$, $T_A(x)$, and $T_T(x)$. We discuss the ambiguity issue along with the optimal distribution of transaction costs before and after approval in section IV.

Transaction costs and uncertainty increase the overall cost of control by absorbing resources directly (T_A and T_T) and by suppressing exchanges that otherwise would have been mutually beneficial.³³ The effects on the overall costs will finally depends on the risk behavior response, the relationship among different variables, and the initial allocation of emission rights. A more conservative agent, for example, will control more pollution in presence of risk -- cases (13) and (13a).

Without defining any functional forms for T_A , T_T and P_s , there are some additional comments. The consequences of transaction costs transaction costs and

³³ The reduction on overall welfare is minimum when the initial allocation of emission rights approaches the least cost-solution. The initial allocation of rights, however, is subject to imperfect information and equity considerations. Optimal allocation of emission rights under imperfect information has been discussed by Pitchford (1993).

uncertainty in the final configuration of pollution-reduction burden among firms may depend upon the initial allocation of emissions rights. We can follow the analysis done by Stavins (1994) and show that the final configuration may be affected only in the presence of either decreasing or increasing marginal transaction costs. Given an initial distribution of emissions rights, decreasing marginal transaction costs can take us a bit closer to the cost-effective solution, while increasing marginal transaction costs can do the opposite. Uncertainty, however, will always drives us far from the original cost-effective solution. Therefore, uncertainty and transaction costs should also be considered in the design of the initial allocation of emission rights.

3.2 Uncertainty and the Conditional Transferable Discharge Permits (TDPs)

We now turn to a second type of restriction on TDP exchanges. It is in the context of a "decentralized" market. Here, the authority indirectly places constraints on exchanges in order to prevent future violations of water quality standards. By using a conditional tradable permit system the authority can account for future changes in watercourse properties. A conditional TDP system can be thought of as a TDP system indexed to the ambient conditions of each period.³⁴ Thus, the number of TDPs issued by the authority for a limited period and this number can either fall or rise in the next period. Unfortunately, under this approach the purchase of TDPs would not be riskless. The initial flexibility given by them can be substantially reduced under this new context of uncertainty about future conditions.³⁵

Flexibility acquires large importance on irreversible investments such as a BOD treatment plant. When the investment decision of building or expanding a treatment plant

³⁴ The length of each period is subject to authority's criteria, but it should be primarily based on stream flow rate and temperature. A six month period may be adequate.

³⁵ David and Joeres (1983) point out that TDPs allow flexibility in operation, which is an advantage that has to be stressed even if it is hard to value in dollars.

can be delayed by purchasing TDPs, there is a flexibility option, which becomes an opportunity cost once the investment is made, that needs to be considered (Pindyck, 1991). The larger the opportunity costs the more attractive TDPs are. However, this opportunity cost may be reduced by the uncertainty in the market. We develop a two-period model that accounts for irreversibility in the investment and uncertainty in future TDP prices.

Consider an individual firm, whose unrestricted BOD discharges are u , facing two complementary options to comply with water quality standards: waste treatment facilities and TDPs. Additionally, consider a conditional TDP system affecting a large number of firms where the authority issues emission rights at the beginning of each period.³⁶ An individual firm receives emission rights equal to q_{01} and q_{02} in period 1 and 2 respectively. While q_{01} is known at the beginning of period 1, q_{02} is unknown and can be bigger or smaller than q_{01} . If at the beginning of period 2 the watercourse conditions have not changed, so $q_{02} = q_{01}$, any individual firm that purchased TDPs in the first period would only need to valid all its permits for next period. However, if watercourse conditions have changed, so $q_{02} \neq q_{01}$, additional TDPs exchanges would be necessary.

It is very likely that TDP prices be subject to change when q_0 varies. Economic activity, population growth and technology innovation can also affect prices in either direction.³⁷ If authority issues more emission rights in the next period, $q_{02} > q_{01}$, the supply of TDPs is likely to increase and prices to fall; and if regulation becomes stricter, $q_{02} < q_{01}$, demand for TDPs is likely to increase and prices to rise. We consider a known price, p_1 , in the first period and an unknown price, p_2 , in the second period. We also

³⁶ A large number of firms is a convenient hypothesis for two reasons: TDP prices can be assumed exogenous to each exchange and they are always available. For the latter think of a new firm entering into a system that have sufficient installed capacity (most existing water systems) to provide permits even under adverse watercourse conditions.

³⁷ Economic growth in the area can drive prices up by making the watercourse disposal capacity more scarce, while technological innovation can drive prices down by decreasing the cost of pollution abatement.

assume that there is no transaction costs in this problem. Their effects were already seen and only will move the equilibrium further from the cost-effective solution.

Another aspect of the investment decision problem is the treatment plant capacity choice. We consider the installed treatment capacity, c , as the maximum amount of BOD the plant can reduce.³⁸ We assume that c is chosen in the first period and remains fixed for the two periods.³⁹ Later in the thesis we comment on this assumption. Capital costs associated with the plant are known and based on the installed capacity c . These costs are equalized throughout the amortization period, thus we have a capital cost equal to $C_C(c)$ for each period (Eheart et al., 1987).⁴⁰ In addition, it is assumed that variable costs associated with plant operation during the two periods depend on the amount of BOD controlled, r . Furthermore, they may be reduced by utilizing only a percentage of the total available capacity c .⁴¹ These variable costs are $C_V(r_1)$ and $C_V(r_2)$, where r_1 and r_2 are the BOD control levels in periods 1 and 2 respectively. As in section 2.1, $C_V(\cdot)$ and $C_C(\cdot)$ are assuming increasing functions in their relevant ranges.

In summary, at period 1 purchaser of TDPs faces the following situation

	Period 1	Period 2
Unrestricted BOD discharges	u	u
Discharge (emission) rights	q_{01}	$E(q_{02})$
Price per TDP	p_1	$E(p_2)$
BOD controlled	r_1	r_2

³⁸ BOD removal rates by treatment facilities usually range from low levels (e.g. 35%) to almost total control (e.g. 98%). A typical treatment train is described in Eheart et al (1987).

³⁹ In some cases level of control can go little beyond the installed capacity by increasing significantly marginal operational costs.

⁴⁰ The length of the amortization period does not make qualitative difference in the results. Eheart (1987) for example considers a 20-year amortization period, and obtains [annualized] capital cost much higher than [annual] operational costs.

⁴¹ The last assumption is important because some types of abatement plants cannot be operated much below design capacity without damaging the biological processes involved.

TDPs purchased	x_1	x_2
Capital Costs	$C_C(c)$	$C_C(c)$
Variable Costs	$C_V(r_1)$	$C_V(r_2)$

where q_{02} and p_2 are random variables, and x_i and r_i are always related by eq. (1) in order to comply with regulations all the time.

In this thesis we are particularly interested in the effects of irreversibility and uncertainty over c . First, we illustrate the case where p_1 and p_2 are known at the beginning of period 1, and where p_2 can be smaller, bigger or equal to p_1 . Later we turn back to the original problem where p_2 is unknown at period 1. Without loss of generality, we consider a profit-maximizing agent that always correspond a purchaser of TDPs for any pair of prices p_1, p_2 . The situation for such a discharger is illustrated in Figure 3. Depending on the conditions of the watercourse, emission rights, q_0 , can vary from q_0^{\min} to q_0^{\max} . This implies that prices as a response to changes in q_0 can move from p^{\max} to p^{\min} . Notice that TDP price increases as the amount of emission rights decreases. Because ranges of variations for p and q_0 do not cross at any point, this firm will always be a purchaser of TDPs (see Figure 3). The analysis can easily be extended for a pure seller of permits or for a mixing one.

For a purchaser of TDPs the two-period wastewater treatment plant design problem is given by

$$\text{Min } TC = C_C(c) + C_V(r_1) + p_1 \cdot (u - r_1 - q_{01}) +$$

$$\frac{1}{1+i} [C_C(c) + C_V(r_2) + p_2 \cdot (u - r_2 - q_{02})]$$

subject to

$$r_1, r_2 \leq c, \text{ and } r_1, r_2 \geq 0, \quad (14)$$

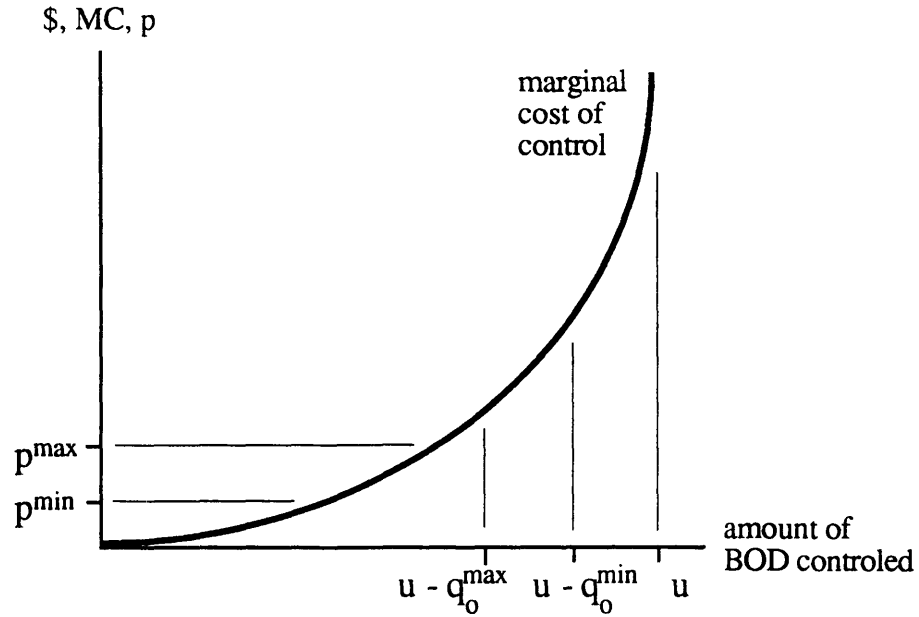


Figure 3. The situation for a "pure" purchaser of permits that receives an amount $q_0^{\min} < q_0 < q_0^{\max}$ of emission rights and faces a TDP price $p^{\min} < p < p^{\max}$. According to the marginal cost of control, this emitting source will always be better off buying permits than rather controlling at higher levels and selling some of them. "u" is the unrestricted amount of discharges.

where TC is the total cost of compliance considering TDPs; c , r_1 , and r_2 are the decision variables; and i is the relevant discount rate. Introducing slack variables, μ_1 and μ_2 , the Langrangean for the above problem is given by

$$\begin{aligned}
 L(c, r_1, r_2) = & C_C(c) + C_V(r_1) + p_1 \cdot (u - r_1 - q_{01}) + \\
 & \frac{1}{1+i} [C_C(c) + C_V(r_2) + p_2 \cdot (u - r_2 - q_{02})] \\
 & + \lambda_1 \cdot (r_1 + \mu_1^2 - c) + \lambda_2 \cdot (r_2 + \mu_2^2 - c),
 \end{aligned} \tag{15}$$

where λ_1 and λ_2 are the Langrangean multipliers. The Kuhn-Tucker conditions lead to the following solution (de Neufville, 1990)

$$\frac{\partial L}{\partial c} = \left[1 + \frac{1}{1+i} \right] \frac{\partial C_C(c)}{\partial c} - \lambda_1 - \lambda_2 = 0 \quad (16)$$

$$\frac{\partial L}{\partial r_1} = \frac{\partial C_V(r_1)}{\partial r_1} - p_1 + \lambda_1 = 0 \quad (17)$$

$$\frac{\partial L}{\partial r_2} = \frac{\partial C_V(r_2)}{\partial r_2} \frac{1}{1+i} - p_2 \frac{1}{1+i} + \lambda_2 = 0 \quad (18)$$

$$\frac{\partial L}{\partial \lambda_1} = r_1 + \mu_1^2 - c = 0 \quad (19)$$

$$\frac{\partial L}{\partial \lambda_2} = r_2 + \mu_2^2 - c = 0 \quad (20)$$

$$\lambda_1 \mu_1 = 0 \quad (21)$$

$$\lambda_2 \mu_2 = 0 \quad (22)$$

$$\lambda_1, \lambda_2 \geq 0. \quad (23)$$

There are three possible cases: (1) $\lambda_1 > 0$ and $\lambda_2 = 0$; (2) $\lambda_1 = 0$ and $\lambda_2 > 0$; and (3) $\lambda_1, \lambda_2 > 0$.⁴² Each case will hold depending on p_1 and p_2 values. It is not difficult to demonstrate that the first case holds when $p_1 > p_2$, the second when $p_1 < p_2$, and the third one when $p_2 = p_1$. First, if $\lambda_1 > 0$ and $\lambda_2 = 0$, we have by eqs. (21) and (22) that $\mu_1 = 0$ and $\mu_2 \geq 0$. This implies that the first constraint is binding. Thus, by eqs. (19) and (20) we obtain that $r_1 = c$ and $r_2 \leq c$. We know that $\lambda_2 = 0$ and that λ_1 can be derived from (17).

⁴² $\lambda_1 = \lambda_2 = 0$ is not a corner solution for a purchaser of permits.

Replacing them into (16), we finally obtain an expression for the installed capacity, c , and the BOD controlled in both periods, r_1 and r_2 , given by

$$(2 + i) \frac{\partial C_C(c)}{\partial c} + (1 + i) \frac{\partial C_Y(c)}{\partial c} = (1 + i)p_1 \quad (24)$$

$$r_1 = c \quad (24a)$$

$$\frac{\partial C_Y(r_2)}{\partial r_2} = p_2, \quad (24b)$$

where $r_2 \leq c$. Similarly, for the second case where $\lambda_1 = 0$ and $\lambda_2 > 0$, we obtain a set of expressions for c , r_1 , and r_2 given by

$$(2 + i) \frac{\partial C_C(c)}{\partial c} + \frac{\partial C_Y(c)}{\partial c} = p_2 \quad (25)$$

$$\frac{\partial C_Y(r_1)}{\partial r_1} = p_1 \quad (25a)$$

$$r_2 = c, \quad (25b)$$

where $r_1 \leq c$. Finally, we have the case where $\lambda_1, \lambda_2 > 0$. In this case the set of equations is given by

$$\frac{\partial C_C(c)}{\partial c} + \frac{\partial C_Y(c)}{\partial c} = p_1 = p_2 \quad (26)$$

$$r_1 = r_2 = c. \quad (26a)$$

Eqs. (24), (25) and (26) are different forms of cost-effective solutions since prices are known. Differences to the original cost-effective solution appear only when prices are

different between periods, because agents care about the unused capacity that might occur when TDP prices fall. This is the irreversibility effect, the fact that capacity in place need not always be utilized. In the first two cases, agents incorporate the irreversibility effect of the investment on the capacity choice formulation by taking into account the marginal cost of unused capacity. Thus, to the original cost-effective solution, a term equal to $\partial C_C(c)/\partial c/(1+i)$ and $\partial C_C(c)/\partial c$ is incorporated into eqs. (24) and (25) respectively. When p is invariant, the irreversibility effect does not take place because there is no unused capacity in either period. The result of incorporate the marginal cost of unused capacity leads to lower levels of installed capacity, c . In other words, capital costs are weighed more than others making agents to rely more in TDPs to comply with environmental regulations.

That is the flexibility that David and Joeres (1983) notices. The value of this flexibility increases as capital costs become proportionally larger than variable costs (He and Pindyck, 1992). Thus, we can expect that TDPs become more attractive as irreversible and larger investments need to be made. However, there is an additional aspect that deserves much attention, that is, uncertainty. We now turn back into our original problem. What happens to this flexibility and the installed capacity, c , when future TDPs prices are uncertain? To solve this problem we consider a price p_1 in the first period and a price p_2 in the second period that will change by θ (positive). With probability q , it will rise to $p_1 + \theta$, and with probability $(1 - q)$ it will fall to $p_1 - \theta$.⁴³ The neutral probability measure is $q = 0.5$ which leads to $E(p_2) = p_1$. We will next show that for all agents that face upward sloping marginal variable and capital costs curves, and a deviation coefficient θ , may have an effect on the capacity choice, c . It may eventually discourage the TDP option by choosing a larger c .

⁴³ This is a simple binomial distribution (independent Bernoulli trials) with step size " θ ".

For the time being we will stay with q , instead of 0.5, because it will help us to understand the effects of different probability on the capacity choice. Thus, the two-period wastewater treatment plant design problem is given by

$$\text{Min TEC} = C_C(c) + C_V(r_1) + p_1 \cdot (u - r_1 - q_{01}) +$$

$$q \frac{1}{1+i} [C_C(c) + C_V(r_2^+) + (p_1 + \theta) \cdot (u - r_2^+ - q_{02}^-)] +$$

$$(1 - q) \frac{1}{1+i} [C_C(c) + C_V(r_2^-) + (p_1 - \theta) \cdot (u - r_2^- - q_{02}^+)]$$

subject to

$$r_1, r_2^+, r_2^- \leq c, \quad r_1, r_2^+, r_2^- \geq 0, \quad (27)$$

where TEC is the total expected cost; r_2^+ and r_2^- are the levels of BOD control for $p_1 + \theta$ and $p_1 - \theta$ respectively; and q_{02}^- and q_{02}^+ are the emissions rights relative to prices $p_1 + \theta$ and $p_1 - \theta$ respectively. We know by eq. (24) that $r_2^- \leq c$ ($p_1 > p_2$), and by eq. (25) that r_2^+ is equal to c ($p_1 < p_2$). Since $r_2^- \leq c$, the Langrangean multiplier associated with it is zero. Thus, our constraints are reduced only the regarded with r_1 . Making r_2^+ equal to c , the Langrangean multiplier of (27) becomes

$$L(c, r_1, r_2^-) = C_C(c) + C_V(r_1) + p_1 \cdot (u - r_1 - q_{01}) +$$

$$q \frac{1}{1+i} [C_C(c) + C_V(c) + (p_1 + \theta) \cdot (u - c - q_{02}^-)] +$$

$$(1 - q) \frac{1}{1+i} [C_C(c) + C_V(r_2^-) + (p_1 - \theta) \cdot (u - r_2^- - q_{02}^+)] + \lambda_1 \cdot (r_1 + \mu_1^2 - c). \quad (28)$$

Solving equation (28) leads to two cases: (1) $\lambda_1 > 0$ and $r_1 = c$, and (2) $\lambda_1 = 0$ and $r_1 \leq c$. Either solution will be valid depending on the value of the different parameters,

including θ . To illustrate the effects of θ , we will only present at this point the solution for both cases. Later, in section IV, we come back to this issue and others related to the differences between both solutions. The solution for the first case is such that

$$(2 + i) \frac{\partial C_C(c)}{\partial c} + (1 + i + q) \frac{\partial C_V(c)}{\partial c} = (1 + i + q) p_1 + q\theta, \quad (29)$$

and the solution for the second case is such that

$$(2 + i) \frac{\partial C_C(c)}{\partial c} + q \frac{\partial C_V(c)}{\partial c} = (p_1 + \theta) q \quad (30)$$

where $\theta > 0$, $i \geq 0$, and $0 \leq q \leq 1$. Notice that for $q = 0$ (certain that price will fall) equations (29) and (24) are identical, and for $q = 1$ (certain that price will rise) equation (30) and (25) are identical.

A curve $c = c(\theta)$ can be obtained by solving the partial differential eq. (29). Since no functional form for C_C and C_V are given, we can only conform with an arbitrary shape for $c(\theta)$. Because C_C and C_V were assumed strictly increasing in c (and r), $c(\theta)$ will be a smooth curve increasing in θ , as shown in Figure 4. Additionally, we include c_e , the cost-effective solution when there is no uncertainty and prices remain unchanged over time. This solution is obtained from eq. (26). In addition, we have that $c(\theta)$ shifts up or down due to changes in q , such as shown in Figure 4. When price is more likely to raise ($q > 0.5$) $c(\theta)$ shifts up, which implies that the flexibility is less worthy. Notice that as q tends to 1 and θ to 0, c tends to c_e . Thus, when price is more likely to rise so do levels of BOD control and costs. The analysis for eq. (30) is similar to the above.

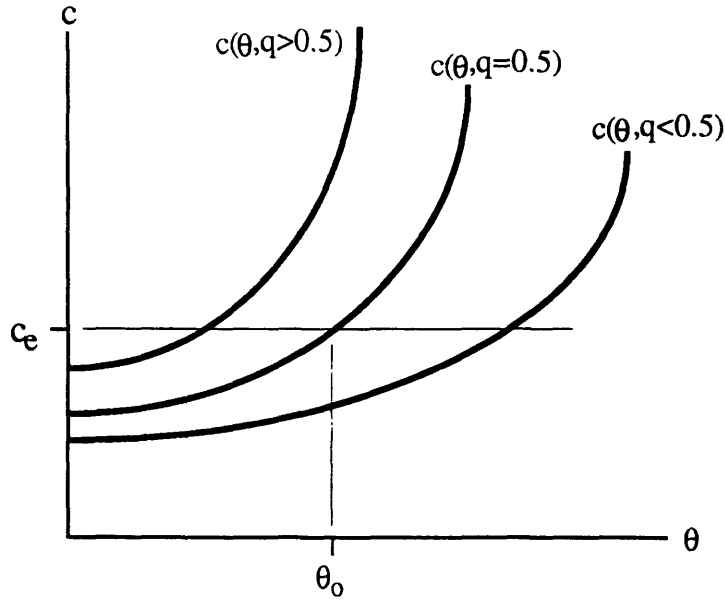


Figure 4. Wastewater treatment plant capacity, c , as a function of price variability, θ , and probability, q ($q > 0.5$ implies price is more likely to rise). The cost-effective capacity choice when price remains constant is c_e .

For an agent that expects prices to remain constant over time ($q = 0.5$), the effects of price deviation θ on installed capacity choice may have different effects depending on its value. There is a value θ_0 , however, where the effect is neutral, that is, the firm installs capacity at the level c_e (see Figure 4). At this point the marginal benefits of the flexibility is equal to its marginal cost. Such as pointed out by He and Pindyck (1992), given the uncertainty over future prices, the more flexible capacity has an obvious advantage, but it is also more costly. In our case, more flexible capacity means more TDPs. Thus, the advantage of using TDPs is in reducing the unused capacity at a minimum, and its marginal cost is simply the permit price. As θ increases the marginal benefit of the option decreases -- because the unused capacity increases (lower r) -- relative to the marginal cost of the option equal to $E(p_2)$. The flexibility net value will only be positive for small

values of θ ($< \theta_0$) where firms will install capacity at level lower than c_e . Therefore, the attractiveness of the option, that is TDP, decreases as price variability increases.

IV. EXTENSIONS

In the preceding analysis we have shown that uncertainty either coming from direct or indirect authority intervention can adversely affect the trading activity in a market for water pollution control. In this section we rather focus on two specific issues associated with these remarks. The first part deals with the effects of the interaction between regulated and regulator on the level of pollution control and the distribution of transaction costs before and after the approval, and the second one with the dynamics of the capacity choice problem.

4.1 Interaction Between Regulated and Regulator

In section 3.1 we concluded that uncertainty has adverse effects on trading activity. Additionally we mentioned that interaction between regulator and regulated can have ambiguous effects on the trading, leading to either higher or lower levels of pollution control compare to the case of no interaction. This ambiguity effects lies on the fact that agents distribute their before and after approval transaction costs differently (T_A and T_T respectively) depending on the "interaction function". For example, if interaction is very sensitive to T_A , agents may be willing to rise T_A and thus improve the expectation of the transfer success. In this part of the thesis, we want to develop this idea of ambiguity a little further. We are particularly interested in two issues: the effects of the interaction function in the amount of TDPs exchanged and the temporal distribution of transaction costs.

Let x (amount of TDP exchanged) be a function of C_A , p , T_A , T_T and P_s , such as $x = x(C_A, p, T_A, T_T, P_s)$. This expression comes explicitly on either eq. (11). On the other hand the interaction function is implicit on $P_s = P_s(T_A, x)$, such as shown in eq. (8). The differential for these functions is given by

$$dx = \left[\frac{\partial C_A}{\partial x} \right]^{-1} dC_A + \left[\frac{\partial T_A}{\partial x} \right]^{-1} dT_A + \left[\frac{\partial T_T}{\partial x} \right]^{-1} dT_T + \left[\frac{\partial P_s}{\partial x} \right]^{-1} dP_s \quad (31)$$

$$dP_s = \frac{\partial P_s}{\partial x} dx + \frac{\partial P_s}{\partial T_A} dT_A, \quad (32)$$

where dx and dP_s represent the total change on x and P_s and respectively. The interaction function expressed on eq. (32) will have no effect on x if $dx = 0$. To find the condition of neutrality we plug (32) into (31) and let $dx = 0$. This latter implies also that $dC_A = 0$. Thus, the condition of neutrality for x can be written as

$$\left[\frac{\partial P_s / \partial x}{\partial P_s / \partial T_A} \right]^{-1} + \left[\frac{\partial T_A}{\partial x} \right]^{-1} + \left[\frac{\partial T_T}{\partial x} \right]^{-1} \frac{dT_T}{dT_A} = 0 \quad (33)$$

where the first terms is the interaction term that appears in (13) as well, and dT_T/dT_A reflects the temporal distribution of transaction costs between after and before approval. Since the first term of (33) is negative ($\partial P_s / \partial x < 0$), the second one positive, and the third one negative (dT_T/dT_A assumed negative),⁴⁴ neutrality can hold under certain set of conditions. As conditions change (33) may turn positive or negative, making x rises or falls respectively.

As an example consider a change in the distribution of transaction costs. If we assume that T_A and T_T are substitute, and increase in T_A drives dT_T/dT_A up (less negative), and with it x . This was expected since more resources are devoted to improve P_s . An increase in T_A also affects $\partial P_s / \partial T_A$ rising x even more. However, the opposite effect can result from the $\partial T_A / \partial x$ term. There is room for more speculation, but indeed, little more can be said since P_s is unknown, and so is the relationship between T_A and T_T .

⁴⁴ A negative slope comes from the fact that T_A and T_T are somehow substitutes.

Were these functions are unknown, we limit ourselves saying that the interaction function may help making the TDP option more attractive. Unfortunately, the opposite is also possible. That is the ambiguity effect.

4.2 Capacity Choice Under a Conditional TDP System

In section 3.2, we left the differences between (29) and (30) and the implications on the capacity choice problem for this section. This analysis will show us how installed capacity and its subsequent use are determined under TDP price uncertainty.

Eqs. (29) and (30) represent two different capacity choice curves, $c = c_1(\theta)$ and $c = c_2(\theta)$ respectively. We will show in a moment that $c_1(\theta)$ and $c_2(\theta)$ are not complementary, and that the optimal path, $c^*(\theta, q)$, is given by

$$c^*(\theta, q) = \max\{c_1(\theta, q), c_2(\theta, q)\}, \quad \theta > 0, \text{ and } 0 < q < 1, \quad (34)$$

where $c_1(\theta, q)$ is the case when $r_1 = c$, and $c_2(\theta, q)$ when $r_1 < c$. Independent of q (you may take the risk-neutrality value 0.5), when θ approaches to zero (but always $\theta > 0$), $c_1(\theta \approx 0)$ becomes greater than $c_2(\theta \approx 0)$, and when θ approaches to infinity,⁴⁵ $c_1(\theta = \infty)$ becomes smaller than $c_2(\theta = \infty)$. Since both curves are continuous, there must be a point, E , where $c_1 = c_2$, such as shown in Figure 5. Making (30) equal to (29) leads to

$$\frac{\partial C_V(c)}{\partial c} \Big|_{c_E} = p_1, \quad \frac{\partial C_C(c)}{\partial c} \Big|_{c_E} = \frac{q\theta}{2+i} \quad (35)$$

where c_E is the point of the optimal path, c^* , where both curves, c_1 and c_2 crosses; and θ_E is the corresponding price deviation. Notice that c_E is always greater than c_e , the cost-

⁴⁵ In reality θ is bounded. We make it large only to compare both cases.

effective solution. To the left of the crossing point, E , $c_2(\theta)$ does not hold because otherwise r_1 , which is given by (25a), would be larger than c . Thus, to the left of E the optimal path c^* is given by $c_1(\theta)$ that is in according to (34). To the right of E , the optimal path is given by c_2 . The latter can be explained assuming you stand on $\theta = \theta_E$ and take an infinitesimal positive increment $d\theta$. To maintain the first order conditions associated with (28) unchanged, we require r_1 to increase by $dr_1 > 0$. This is only possible when r_1 is not bounded by above, that is, when $r_1 < c$.⁴⁶

Even though we are in a more conservative situation regarding capacity choice (larger c), all the qualitative analysis in part 3.2 regarding benefits and costs of the flexibility of using TDPs apply similarly here. In summary, for smaller variations in price, all the installed capacity is expected to be used during the first period. However, as price variability increases agents may rather chose bigger installed capacity to cover future TDP price fluctuation even though some of this capacity is not used in the first period -- TDPs are more convenient. Finally, we still can have the situation of dischargers installing treatment capacity at levels lower than the cost-effective solution. For these firms the flexibility option values more than its cost. Were the latter is possible, transaction costs -- not considered in this part of the thesis -- must be very low, something that is not likely to happen. In summary, indirect authority intervention by indexing emission rights to ambient conditions and natural price variability may induce agents for more conservative capacity design and consequently to disregard trading options.

⁴⁶ See *supra* note 39. If r can be extended beyond c , $c_1(\theta)$ can still hold a little further to the right of E , but most probably we will have a new curve in between due to the increase in marginal operational costs.

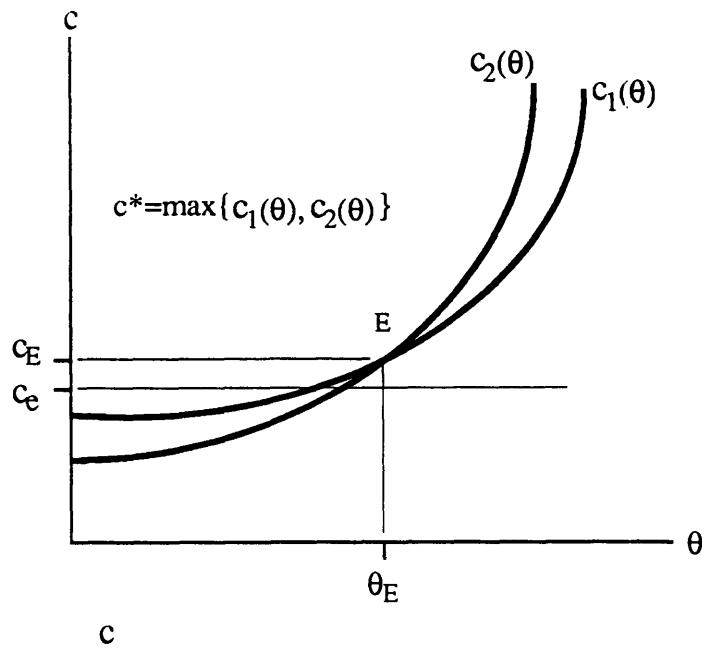


Figure 5. The installed capacity choice, c^* , and the capacity use problem under conditions of irreversibility and TDP price variability. For low values of θ ($< \theta_E$) there is no unused capacity during the first period (c_1 holds), while for high values of θ ($> \theta_E$) there is some unused capacity in the first period (c_2 holds). Notice that the capacity use for the second period will depend on p_2 .

V. POLICY IMPLICATIONS AND CONCLUSION

Should transferable discharge permits (TDPs) be considered as a feasible mean to attain water quality goals in spite of unsuccessful attempts and adverse factors? Although the answer is obvious, questions will arise in the design and assessment process. Uncertainty was shown to have adverse consequences in the market performance. Its implication from a public policy perspective and other issues related to market design are addressed in this section. We start from an overview of the limitations and advantages of marketable permits in environmental regulation, to some comments on design issues and final remarks.

The enthusiasm for using marketable permits (at least as a complementary regulatory mechanism) for different environmental problems is increasing. There are further attempts to use them in the water sector. Recent evidence indicates that nonpoint source pollution from urban and rural areas has increased relative to point source pollution (industrial facilities and wastewater treatment plant), and that in some cases little improvement in water quality can be achieved by only tightening point sources. Pollution trading between point and nonpoint sources appears as a feasible option at a minimum cost (U.S. EPA, 1992). In addition, there are suggestions for using a permit system to control CO₂ emissions (Bohm, 1992). Much of the support for this approach over traditional command-and-control instruments comes from the fact that the former can attain the same environmental quality goals at a much lower costs. Efficiency and cost-effectiveness, however, are by no means the unique criteria for judging environmental policies (Hahn and Stavins, 1992).

Under conditions of uncertainty and transaction costs cost-effectiveness can decrease and others aspects such as equity, political feasibility, ease of implementation, and technology innovation, may claim in favor of more uniform approaches.⁴⁷

⁴⁷ Inequity in a TDP system may rise, among others, from the fact that new sources does not receive emission rights and concentration of damage (hot spots).

Technology innovation, for example, have been lately recognized as the primary goal for pollution control and more importantly for pollution prevention. In that context, economists continue to claim that market-based instruments provide larger incentives for the development and adoption of new pollution control technologies. Much of it lies in the fact that innovation is more responsive to dynamic regulations such as market-based approaches. However, like in a TDP system, the absence of trading may depress incentives for innovation. In summary, typical estimate gains from trading (e.g. Tietenberg (1985)) need to be reassessed. The model presented here is such an attempt.

In designing any environmental policies for water pollution control, policymakers will face a multiple-objective decision problem. As we reduce the problem to efficiency and environmental quality considerations the TDP option receives more attention. In addition to the market setup, the authority can require direct or indirect market intervention to prevent future violations of water quality standards. The Fox River program, in Wisconsin, is a case of direct intervention in the form of ad hoc approval (EPA, 1992; and David and Joeres, 1983), and a conditional TDP system (Eheart et al., 1987), where emissions right are indexed to ambient conditions is an example of indirect intervention. In either system transaction costs and uncertainty can be significant adverse effects in the trading activity such as shown in this study.

Transaction costs have shown to be significant in different markets for pollution control. The magnitude and nature of transaction costs is likely to differ from case to case. As we move from simpler permits designs (e.g. inputs and emissions) towards more sophisticated ones (e.g. ambient, exposure and risk) is expected to have greater public costs associated with monitoring and enforcement and greater private transaction costs (Stavins, 1994). Since more sophisticated approaches allow more control of standards violations (e.g. an ambient BOD permit system) but also higher transaction costs (in any form) there is no simple answer.

Some general suggestion to reduce transaction costs are: increasing the scale of individual transfers (fixed transaction costs are reduced), reducing opposition to exchanges, providing greater dissemination about potential buyers and sellers and thus help sources to identify one another, establishing periodic data reports that would bring information about existing and potential exchanges among all parties, and finally providing broader brokerage services aimed to legally and technically assist interested parties. Some of the suggestion for decreasing transaction costs also would seem to increase the probability that transfer attempts will be successful. Other suggestions for decreasing transaction costs, such as increasing the volume of TDPs in each exchange, might actually increase uncertainty and hence reduce the probability of success (Lund, 1993).

Uncertainty comes in different forms and some are more damaging to the market strategy than others. There is uncertainty associated to the approval process and to technical conditions (e.g. droughts). Establishing firmer regulatory and legal guidelines for both the TDP exchange and third-parties compensation and bargaining processes, risks should decrease and attempts for transfers should rise. Notice that some of these measures may also increase transaction costs but the net effect is expected to be positive. On the other hand, the authority should assume some of the risk of future violations by setting a water quality schedule that could allow eventual violations under adverse watercourse conditions and thus help to keep the interest of discharges in TDP options.

With respect to the institutional aspects of market structure, the primary indication is that permits markets in the case of water are thin (O'Neil, 1980; and Eheart, 1980). As the number of potential traders decreases so does cost effectiveness of the permit system. Consequently planners may wish to define the markets broadly and attempt to include as many agents as possible. However, as the market is expanded, the probability of quality standards violations (e.g. DO levels) due to trading increases (O' Neil, 1980). Again, there is no one answer.

Before a practicable policy of TDP may be implemented, its legal feasibility, procedure for enforcement, and the detailed administrative structure must be determined. This will substantially differ from case to case. Perhaps, we should start from those programs that are more likely to succeed.⁴⁸ We need to learn from encouraging experiences and thus increase the support from policymakers and the general public towards alternative solutions for the water pollution problem and others as well.

⁴⁸ For example, O'Neil (1983) suggested in his study that the cost differential between the market solution and alternate strategies appears so large that even serious operational difficulties may be unlikely to erase the advantage of the market.

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APPENDIX

To understand the theory of a marketable permit system let us first consider N polluters emitting u_i units of emission each (e.g. kg/day of BOD)^a in the absence of any control (u_i is the unrestricted emissions level for source i). Furthermore suppose that the pollutant concentration K_R (BOD level in mg/l) at some receptor point R in the absence of control is

$$K_R = \sum_{i=1}^N a_i u_i + B \quad (A1)$$

where B is the background concentration and a_i is the transfer coefficient associated to source i .^b Since K_R is supposed to be greater than L_R , the legal concentration level, the regulatory problem becomes to choose the cost-effective level of control r_i for each of the N sources in the system. The authority rather than choose these levels by itself it will establish a marketable permit system. The cost-effective solution obtained from the tradable permit system can be derived by the following minimization problem

$$\begin{aligned} \min \quad & \sum_{i=1}^N C_i(r_i) \\ \text{s.t.} \quad & \sum_{i=1}^N (u_i - r_i) a_i = L_R \end{aligned} \quad (A2)$$

^a Emission is the product of the concentration of pollutant in the effluent (mg/l of BOD) and the load of effluents (lt/day).

^b The background concentration may come from sources aout of the system under consideration. The transfer coefficient represents the relative impact of emissions at “ i ” on location R . The larger a_i the larger the impact relative to other location. When location does not matter all transafer coefficients are equal to the unity. If you wish assume $B=0$ and all a_i equal to 1).

where $C_i(r_i)$ is the cost of achieving the r_i level of control at the i th source. Introducing the Lagrangean multiplier, λ , the minimization problems becomes

$$\min \sum_{i=1}^N C_i(r_i) + \lambda \left[\sum_{i=1}^N (u_i - r_i) a_i - L_R \right] \quad (A3)$$

and the solution is found by partially differentiating (A3) with respect to λ and each of the r_i 's. This yields

$$\frac{\partial C_i(r_i^*)}{\partial r_i} - \lambda^* a_i \geq 0, \quad i = 1, 2, \dots, N,$$

$$\sum_{i=1}^N (u_i - r_i^*) a_i = L_R \quad (A4)$$

Solving these equations produces the N -dimensional vector r^* and the scalar λ^* .^c

There is an important meaning attached to λ . If transferable permits were being used, it would be the market clearing price of a permit that allow to emit such an amount that raise the concentration at the receptor location one unit. Given this "price" of pollution permit, λ , notice how firms choose emissions control. Each firms is assumed profit maximizer, so they will try to minimize cost of pollution control. Assume that each firm is given an initial amount of permits equal to q_{oi} , where the regulatory authority ensures that

$$\sum_{n=1}^N a_i q_{oi} = L_R \quad (A5)$$

for all emitters in the system. A i th profit maximizer firm would want to

^c In the case of J receptors a_{ij} would become a $N \times J$ matrix, and both L_R and λ^* would become J -dimensional vectors.

$$\min C_i(r_i) + p^* \cdot ((u_i - r_i) a_i - q_{oi}) \quad (A6)$$

and the solution will be given by

$$\frac{\partial C_i(r_i^*)}{\partial r_i} - p^* a_i = 0. \quad (A7)$$

This condition (marginal cost equals the price of a unit of concentration reduction in a point R of the receptor) would hold for each of the N firms. Because p^* would equal λ^* and the number of permits would be chosen to ensure the ambient standard [in R] would be met, this allocation would be cost-effective. Notice that when transfer coefficients a_i ($i=1, \dots, N$) are different across sources the marginal cost of pollution control is also different. On the other hand, if transfer coefficients are equal to the unity all sources will control at the same marginal costs equal to p^* .